Geodynamics monitorization using wireless sensor networks

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***Abstract*—A wireless sensor network application used to monitor earthquake and assess risk of urban damage**

Wireless sensor networks are a cheap and versatile solution for monitoring various environments and elements of an environment. There exists a number of such applications used worldwide to monitor areas in which human access is hard or near impossible. The issue with these applications is that they are mainly used by government organizations or for research purposes. They seldom focus on using the data in the interest of safety for the population, such as warning them of natural disasters or assessing the risk of damaged areas left in the wake of a natural disaster. The solution we propose in this article is used to monitor earthquakes and the status of urban structures exposed to earthquakes or other sources of vibration in order to prevent possible disasters.

***Index Terms*—Wireless Sensor Networks, Geodynamics, Earthquake monitoring, Low power**

I. Introduction

In recent years, wireless sensor networks have been used more and more often as a cheap and easy to maintain monitoring system. Wireless sensors are adequate tools for monitoring various environments due to a series of characteristics such as: low power consumption which increases autonomy and helps reduce the node size (no need to attach large batteries), the possibility to attach energy harvesting modules which further help to increase their autonomy and the ability to mount numerous sensor peripherals on a small surface.

Since these sensors communicate via wireless networks, they are ideal tools to use in monitoring remote or otherwise hostile environments such as: underground caverns, ocean floors, volcanic mountain ranges, etc. Another field in which wireless sensors would represent a good monitoring solution is geodynamics. Using such a network, it could be possible to predict natural phenomena such as earthquakes, tsunamis, landslides and volcanic eruptions much faster and with increased precision regarding magnitude and the time of the event. Also, such a solution may prove to be cheaper and more flexible than existing installations deployed for performing these tasks.

Delving even deeper into the utility of such an application, we can take into account that whenever a phenomena amongst those mentioned earlier occurs, the areas which often suffer damages are cities and towns. A good use for a wireless sensor network would be to mount it around cities and on buildings inside the city situated in such danger zones. Thus, whenever an earthquake or other natural disaster occurs, authorities can respond faster and reduce the damage, both material and human lives.

In this paper, we propose a wireless sensor network solution for monitoring earthquakes. The nodes can be mounted on buildings and they will monitor the vibration of the building as well as various other parameters (air pressure, temperature, etc.). Once calibrated to the "normal" values of the parameters, whenever these parameters go over a threshold value, a system is notified that there is a possible risk of an earthquake happening. More so, this system can be used to determine if a building is exposed to deterioration due to external factors such as proximity to construction site, roads frequented by heavy load trucks, etc.

II. Related Work

Applications which monitor geodynamics using wireless sensor networks have been attempted before. However, most have been used to monitor volcanic activity, tsunamis and building structure integrity but there are seldom any references of attempts to monitor earthquakes directly using wireless sensor networks.

Researchers from Singapore, China and the USA have published a paper describing their implementation of an improved algorithm for WSNs in order to monitor volcanic activity. This new algorithm, using data gathered from the sensors, would determine as accurately as possible and in real time the arrival of primary seismic waves which are produced prior to a volcanic eruption. Although not directly focused on earthquake monitoring, this research provides a starting point for further research and improvements in this area.

Another implementation using WSNs is presented in an article by N. Meenakshi and Paul Rodrigues [2] and focuses on tsunami monitoring using WSNs. They propose a network composed of 3 types of nodes: sensors, commanders and barriers. The sensors are dispersed underwater to monitor the water pressure. This data is sent to commanders which process it and determine if there is any specific area in danger of being hit by an incoming tsunami, determined by the variations in pressure. If there is any danger, the barrier sensors in that area are notified to activate the barriers.

One more direction in which geodynamics monitoring WSNs have been used is structural integrity of buildings [3]. Especially in urban areas, buildings are often exposed to vibrations caused by various factors: heavy vehicles such as public transport or cargo trucks, proximity to construction sites, etc. In time, such buildings deteriorate and become a danger because they are prone to collapsing. Using such sensors to monitor the vibrations they are exposed to, damage can be prevented by determining if a building is prone to collapsing and if it poses a threat to people and other structures in the area.

III. Architecture

The SparrowE wireless sensor nodes are custom designed for use in various research projects. They are designed as a single PCB board which hosts all of the major components, such as: controller, RF module, power supply and sensors. The main the main processing unit of the SparrowE nodes is an Atmega ZigBit 900MHZ RF module, which hosts both the microcontroller, an ATmega 1281V 8-bit microcontroller and the wireless transceiver, an AT86RF212 RF chip. These two components are connected via an SPI line inside the ZigBit module. The 8 bit, low power, Atmega 1281V microcontroller is connected to all of the node's sensors and its main function is to process the data received from them and pass it on to the RF transceiver. The AT86RF212 RF is a low power wireless transmission chip capable of sending signals to distances of up to a few kilometers, according to the official datasheet [**?**]. It also provides an AES-128 compatible security module for data encryption and decryption.

Figure 1. SparrowE wireless sensor nodes

In order to monitor its environment, the SparrowE wireless sensor node relies on 3 main sensor peripherals. The first is an Si7020 humidity and temperature sensor with incorporated ADC unit. The measurement resolution for relative humidity measurements can vary between 8 and 12 bits, while the resolution for temperature measurements varies from 11 to 14 bits. The second sensor is an MPL3115A2 altimeter which can measure pressure and altitude. This sensor also has an incorporated ADC unit and can measure both altitude and pressure with a precision of up to 20 bits. The final sensor mounted on the SparrowE and the most important for earthquake and vibration monitoring is the LSM9DS0 IMU(Inertial Measurement Unit). This chip has 3 channels for linear acceleration measurement, 3 channels for angular rate measurement and another 3 channels for magnetic field measurement. All data measurements are performed at a 16 bit resolution. From this last sensor, the metric used by the presented application is the linear acceleration (measured in Gs). All of the aforementioned sensors are connected to the microcontroller via a two-wire interface. Each of the has a different slave address so it is possible for the master, the Atmega 1281V controller, to communicate with all of them without interference from the others.

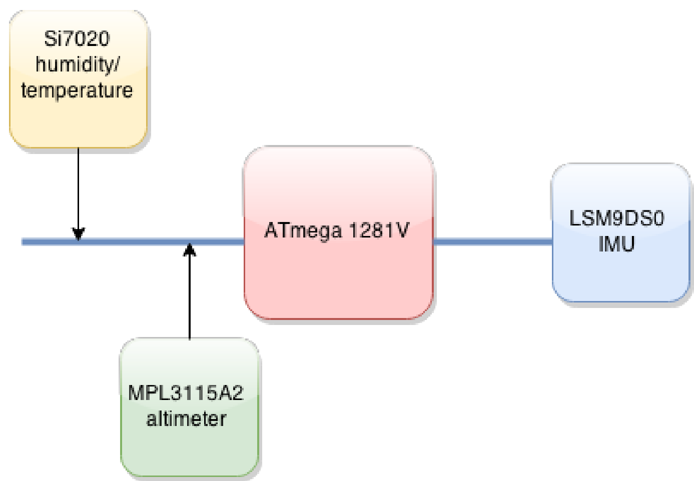

Figure 2. Sensors connected on two-wire interface

All the components on the SparrowE node function at a maximum supply voltage of 3.6V. The node can be powered in 2 ways: either from a lithium polymer battery cell or via an USB port. When powered via USB, a linear DC regulator is used to drop the supply voltage from the 5V of the USB line to the necessary 3.3V.

A. Software

The SparrowE wireless sensor nodes software follows the same design ideea as in the case of the hardware, so in order to write code more easier, the node's firmware is a moddified arduino compatible firmware. Arduino[1] is an open-source cross-plaftorm idee. This allows us to be platform independent, because arduino is available for all three major platforms, Windows, Linux and Mac. Another advantage is that the same code could be used on a different hardware without major modifications.

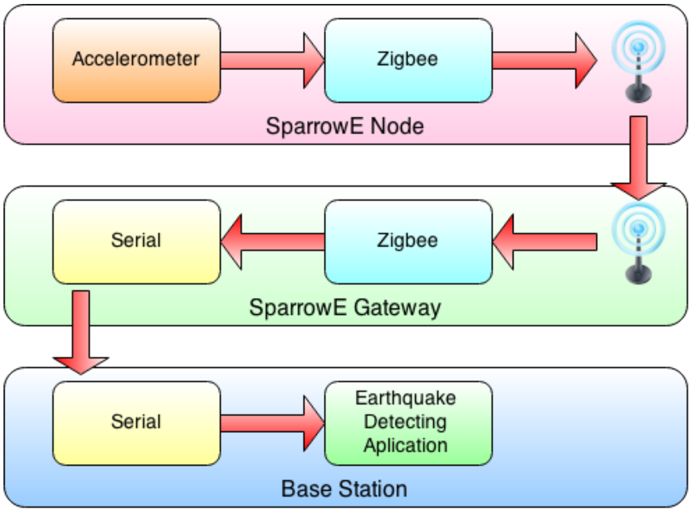

Figure 3. Software arhitecture connections

The accelerometer of the node is configured for a +/-2G linear acceleration rate and an Ouput Data Rate of 50 Hz. The raw data from the 3 axis is translated into gravitational scale and then is normalized using the bellow formula:

$$a = \sqrt{x^2 + y^2 + z^2}$$

This approach will generate a value of 1G when the node is not shaken and when it is vibrating, the value will higher or lower then 1g. The calculated data is gather in an array of 20 that is sent periodicaly by the Transceiver to the Gateway, alongside node identification data. The Gateway is able to collect data from multiple nodes and send it to a base station through a serial connection configured at 1 Mbps baud rate. The base station is responsible for saving and interpreting the data. An earquake is detected when the values will oscilate strongly around the 1G value.

IV. Experimental setup

In order to test the accuracy and capability of the SparrowE wireless sensor nodes, we have built a shake table in order to simulate the movements of a building during an earthquake. The purpose of the experiment is to see if the SparrowE nodes can detect the main waves which are felt during an earthquake, P-waves and S-waves.

P-waves stands for Primary Waves and is a type of seismic wave produced when an earthquake occurs. Amongst seismic waves, it has the highest velocity, making it the first wave which is recorded by conventional seismographs. This wave is formed by alternating compressions and rarefactions of the material and its mode of propagation is always longitudinal. The other type of wave which can be recorded during an earthquake is the S-wave which stands for secondary or shear wave. S-waves move in a transversal manner through the body of an object, thus resulting in motion which is perpendicular to the direction of wave propagation.

The experimental setup tries to emulate the effects of these waves on a tall building which has SparrowE nodes mounted on its sides. The purpose of the experiment is to see how accurate the data harvested by the IMU is and how the amplitude of the movement varries from floor to floor.

Figure 4. SparrowE wireless sensor nodes mounted on the experimental rig

In order to perform the experiment, an experimental rig was built. This rig uses a movable frame as its base, and a tall, layered shelf mounted on top of it. The frame is composed of two individual planes which are moved individually by two DC motors. One plane produces left-right movement, while the other moves the shelf forward and backward. The planes are connected to the corresponding motor via a crank whose length can be adjusted, thus giving the ability to control the amplitude of the movement. Smaller amplitudes will result in sudden and violent shakes while higher amplitudes will allow the shelf to sway more. The schematic of the movable frame is presented below:

During the experiment, we harvest the accelerometer data from the SparrowE sensors' IMU at various movement speeds. The movement speed is controlled by the supply voltage on the motors. The supply values we chose for the experiment are 2V, 4V and 7V.

V. Results

The test were conducted using a gateway connected to 4 nodes. The nodes were place each on a shelf in order to see if the

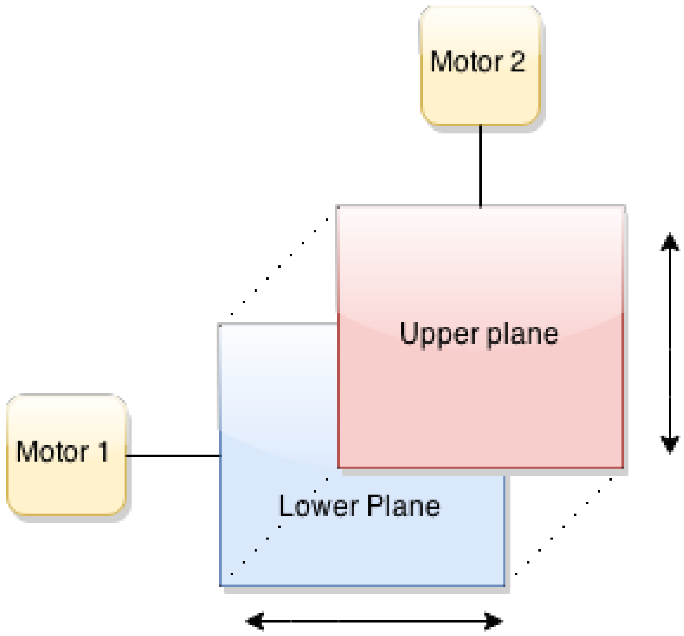

Figure 5. Experimental rig moving frame diagram

height of the shelf might replicate a tall building. The nodes needed to be mounted securely, otherwise the data would have been courupted. This applies to the real world, where the nodes will need a sturdy mounting place to properly sence any vibrations in the structure of the building.

We have conducted 3 tests by seting the shake table at different voltages and the same ammount of vibration time of 3 seconds.

- Test at 2v. This test will demonstrate that even when the table is barely vibrating in order to simulate a small eartquake, the nodes are capable of detecting it.
- Test at 4v. This is a more stronger test.
- Test at 7v. This generates powerfull vibrations which help us see if the limit of +/-2G set on the nodes can be reached.

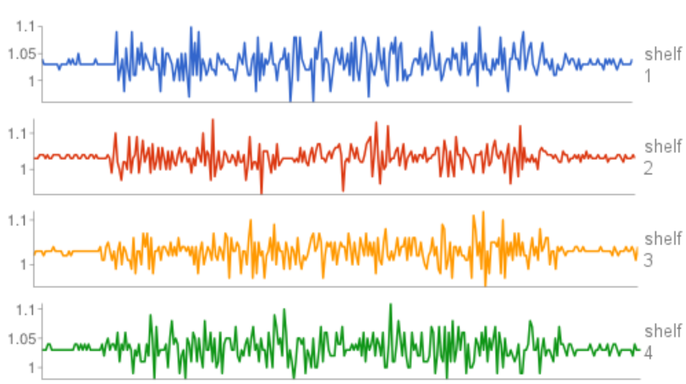

Figure 6. Results for the shake table at 2V

As it can be seen in figure 6, figure 7 and figure 8, the value range when the table is still is around 1G with a diference

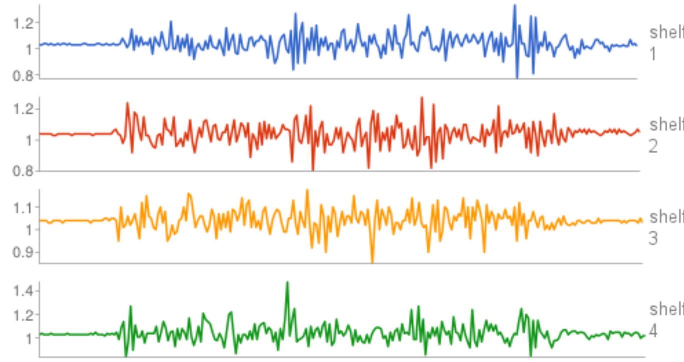

Figure 7. Results for the shake table at 4V

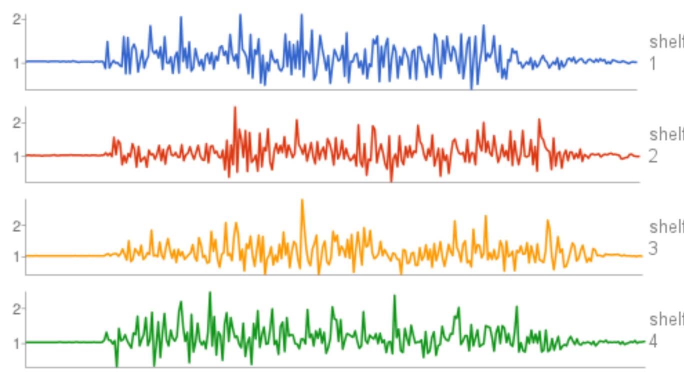

Figure 8. Results for the shake table at 7V

of 0.04G. Any value that is higer or lower than that and is relatively periodical can be interepreted as an eartquake.

The results prove that the experimental rig is responding similar to a tall building because the lower positioned nodes gather stronger values then the ones located on higher shelfs when the table is vibrating. In the end of the simulation, when the table is not shaken and it is naturaly vibrating due to previous forces, the higher positioned nodes continue to detect vibrations, as it should have happened in the case of a real building.

VI. Conclusions and Future Work

A. Conclusions

In this paper, through the previously presented experiment, we have shown that the SparrowE wireless sensor node is a viable tool for monitoring earthquake activity. It is also versatile as it can fulfill multiple purposes and tasks. SparrowE nodes can be placed in key points on a structure to monitor the amount of vibrations which it is exposed to. Alternatively, the nodes can be organized in a wireless sensor network and can be used to monitor seismic activity in certain areas. They can act as a tool which is used to predict earthquakes and warn authorities in case of danger.

Furthermore, because the sensor nodes are low power, no matter in which type of application they are used, they will be able to function for prolonged periods of time, which makes them ideal for monitoring environments.

B. Future Work

The SparrowE sensor nodes can be further improved by adding energy harvesting modules to their current design. Allowing them to harvest resources such as solar power can further increase their autonomy and efficiency. Improvements can also be made to the experimental rig. A collaboration with experts in seismology would be ideal in order to properly calibrate the rig to simulate proper earthquakes on the Riechter scale and produce more accurate movements.

VII. Acknowledgements

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